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Material - Adhesives - Structural

Effect of Testing Variables on Tensile Shear Strength

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Material - Adhesives - Structural

Effect of Testing Variables on Tensile Shear Strength

Abstract:

The effects of (1) relative atmospheric humidity; (2) rate of loading test specimens; (3) removal of excess test specimen flash; (4) bonding press pre-heating; and time lapse from bonding to testing were determined. Tapes which were subjected to high relative humidity showed decreased tensile shear strength. Strength increases appeared to increase when testing speeds were doubled. Flash removal enhanced tensile shear strength results. No significant differences in test result occurred between tests prepared with cold or pre-heated presses. Time lapse variations between curing and testing were not significant in test results.

Reference: Bergstron, B. E. Picotte, G. L., Keller, E. E., "A Study of Some Variables in the Preparation and Testing of Tensile Shear Specimens," General Dynamics/Convair Report MP 57-896, San Diego, California, 18 August 1958 (Reference attached).

STRUCTURES - MATERIALS LABORATORIES

CONVAIR

A DIVISION OF GENERAL DYNAMICS CORPORATION

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REPORT 57-896

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MODEL 22

TITLE

REPORT NO. 57-896

A STUDY OF SOME VARIABLES IN THE PREPARATION AND TESTING OF TENSILE SHEAR SPECIMENS

MODEL 22

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Report No. 57-896
A Study of Some Variables in the Preparation and Testing of Tensile Shear Specimens

I. INTRODUCTION

It has been known for some time that many variables are involved in bonding a metal such as aluminum to itself. A survey on currently used methods for cleaning, assembling, curing and testing adhesives showed that numerous varying procedures were being used by manufacturers and processors.

To improve the results obtained in tensile shear testing of metal-to-metal structural airframe adhesives, a standardized technique was requested by Mr. Seth Gunthorp. This technique was to be determined after preparing and testing a series of specimens under known conditions.

The knowledge of the many variables involved should be greatly augmented by this study. It will permit the selection of a simple workable method for testing metal bonded surfaces that are properly and uniformly prepared.

At the request of the Materials & Processes Laboratory, Mr. Fred Lemus of Engineering Reliability Group designed a fractional factorial experiment to permit the accurate calculation of the effect of five variables related to the preparation and bonding process of the Metlbond 4021 System. The statistical analysis of variance techniques and calculations used by Mr. Lemus are discussed, by him, in Section XI of this report.

II. OBJECT

A. To determine the effect of the following variables on tensile shear strength of Metlbond 4021 tape at 75°F, -67°F, and 300°F.

1. Relative atmospheric humidity
2. Rate of loading the test specimen
3. Routing off excess flash on test specimen
4. Pre-heating the bonding press
5. Time lapse from bonding to testing.

B. To incorporate the information obtained during the test into a workable standard procedure for the preparation and testing of tensile shear specimens.

III. CONCLUSIONS

A. The tensile shear strength values obtained in this test were more reproducible than day-to-day analogous quality control tests. This was expected because five of the suspected variables were accounted for and subtracted from the experimental error.

1. Tape subjected to a high relative humidity will show a decreased tensile shear strength.

2. There appears to be an increase in strength values when a load rate of 2400 psi/minute is used in place of the current 1200 psi/minute.

3. Flash routed off before testing affects tensile shear strength. Greater loads before failure are possible when routing is done.

4. There appeared to be no significant difference between using a cold or pre-heated (300°F) press.

5. The aging at room temperature of cured specimens before physical tests are made is not a significant variable.

B. A workable procedure for the preparation and testing of tensile shear specimens can be summarized from Sections VI and VII, and the Recommendations (Section IV) of this report.

IV. RECOMMENDATIONS

A. Based on the work reported herein, it is recommended that:

1. Better results in tensile shear testing would evidently be obtained by keeping the relative humidity as low as possible. This, however, is not as easy as one may first think because our proximity to the salt water leads to above average moisture in the air. The easiest way that traces of moisture can be minimized is by storing the tape in an air tight container containing a desiccant, and avoiding unnecessary exposure to the air while the tape is in the uncured state.

2. It would be advantageous (where permissible) to use a 2400 pound per square inch per minute rate of loading for testing tensile shear strength. Such a rate will increase the tensile shear strength readings, save time and free the testing machine for other applications. This rate is in accord with that specified in the proposed revisions of MIL-A-8431 paragraph 4.3.4.1.

IV. RECOMMENDATIONS (Continued)

3. Routing off flash from cured specimens appears to warrant recommendation for shop application. However, some re-designing of the router would be necessary to prevent scratching and gouging of the aluminum. A present investigation concerns removal of flash with the tip of a soldering iron. Additional investigative work should be done on routing to determine whether shop production application would be justified and practical.

4. Pre-heating a press for bonding is not necessary and may lead to voids caused by entrapped gases. It is more practical to start with the press at room temperature and allow a slow heat rise to occur, thereby permitting volatiles to escape without forming air pockets or voids in the bond.

5. Although aging of the cured specimens does not significantly alter their tensile shear strength, no unnecessary delays from bonding to testing should be tolerated. Delays can generally be avoided by efficient scheduling of the tests in advance.

B. The methods of cleaning, lay-up and testing used in this experiment should be made a standard procedure. (Sections VI and VII of this report)

V. FUTURE WORK

There are some phases of the preparation and testing of tensile shear specimens which should be cleared up by further investigation. It is suggested that future work be done on (1) types of bonding pads; (2) methods of clamping specimens; (3) use of temperature and pressure programmers during bonding; and (4) factors associated with the aluminum sheet itself.

VI. DESCRIPTION OF SPECIMEN

Panels 4"x9" were prepared in sufficient quantities from 0.064" alclad 2024-T3 aluminum alloy sheet conforming to Specification QQ-A-362. Thickness tolerance was held to 0.064 ± 0.002 inch, a value which well met the .005 inch allowed by MIL-A-5090B.

All edges of the test panels which were to be within the completed bonded lap-joint were milled true and smooth before the panels were cleaned and bonded. Panels were protected during machining operations by using Protex No. 5 protective paper CVAD TAP 50-40. A decision was made to test 28 specimens for each of three temperatures representing four different joints. Each pair of bonded 4"x9" panels yielded seven 1-inch wide specimens.

VI. DESCRIPTION OF SPECIMEN (CONTINUED)

All test panels were lapped 1/2 inch in such a manner that the area to be bonded was flat within the 0.005 inch/inch tolerance permitted by MIL-A-8431. This condition of flatness was verified by means of a straight edge.

A. Surface Preparation of Test Panels

1. Panels were handwiped twice with clean cheesecloth saturated with methyl ethyl ketone (TT-M-261) and allowed to air dry for 10 minutes.

2. Bonding surfaces of the degreased panels were immersed in a modified FPL etching solution consisting of the following parts by weight:

10 Sulphuric Acid C.P. Sp.Gr. 1.84
4 Sodium Dichromate
30 Water - Distilled

Panels were immersed in the sodium dichromate - sulphuric acid solution for 10 minutes at 150 to 155°F. Agitation of the solution was stopped prior to immersion of the parts.

3. Within 2 minutes of removal of parts from the solution, they were spray rinsed thoroughly with tap water for 3 to 5 minutes.

4. Parts were then spray rinsed for 1 minute with room temperature distilled water and checked for a water break-free surface.

5. Within 30 minutes of the last rinse, the parts were dried in a vented oven at 140-150°F for 10 minutes. Parts were dried with their etched surface vertical, to preclude formation of droplets on edges to be bonded. Precaution was taken during surface preparation of the test panels not to touch etched areas to each other or with the operator's white gloves.

B. Priming

1. Primer was placed in a paint shaker for 10 to 15 minutes.

2. One prime coat of Metlbond 4021 Type II was brushed on the clean, dry aluminum faying surfaces to a thickness of 0.7 to 1.3 mils. The coating was extended at least 1/4 inch beyond the area to be overlapped.

3. Coating was air dried 10 minutes at room temperature followed by a pre-curing of 30 minutes at 250°F in the oven.

4. Pre-cured panels were allowed to cool to room temperature, wrapped in kraft paper and stored until used.

VI. DESCRIPTION OF SPECIMEN (Continued)

C. Lay-Up

1. Strips of Metlbond 4021 tape were cut from the roll to be tested by using a scapel and aluminum template 5/8"x10"x.064". White cotton gloves were worn by the operator when cutting the tape and removing the backing.

2. Some strips were placed in a desiccator containing Drierite for a period of 24 hours prior to bonding. Other strips were cut from the roll immediately prior to bonding. The roll was kept wrapped in polyethylene, in its original container, and opened only for sampling.

3. Pre-cut strips were placed on the area of the panel to be bonded. Placement was facilitated by using an aluminum jig. The tape was maintained firmly in place by tacking for 10 seconds with a warm (160-170°F) tacking iron. Length of overlap joint was controlled to 0.50" ± .01" in confirmance with MIL-A-5090B. A 1/16"x5/8"x9" piece of silicone rubber was placed between the lap joint area and press platten to equalize the pressure distribution.

D. Curing

1. Specimens were cured at 100 psi in an electrically heated triple platen K-M press for one hour at 350°F. The press was pre-heated to 300°F before inserting one group of specimens. A second group of specimens were cured starting with a cold press; measuring the curing cycle from the time when 350°F was reached. All specimens were cured in place in the bonding jig previously used for lay-up.

2. Specimens were removed from the press immediately following curing and placed on end to cool to room temperature.

E. Sawing

1. A circular table saw was employed to cut the bonded panels into seven 1"x7-1/2" size specimens. The outer 1/4" edges of the original panels were trimmed off and discarded. Specimens were randomized, as far as practicable, and identified by means of a Vibra-tool.

2. The saw blade used in the above operation had a 10" diameter and 72 carbide tipped teeth. It was fabricated by the Kennametal Co. of Latrobe, Pa., under the designation 10 LF 72. Utmost care was used in sawing panels so as to hold the frictional heating of the bond to a minimum. It was not necessary to machine the edges of the sawed specimens to an RMS of 160 in the bond area. The specimens showed an RMS of 100 microinch in the sawed condition, as determined by using a Microfinish Comparator Cat. No. S-22 manufactured by Baptist Machine Company, Inc. of Stamford, Connecticut.

VII. TEST PROCEDURE

A. Tables VI and VII show that four groups, each containing seven specimens, will result from sawing the four bonded .064"x4"x9" pairs of panels. These four groups are dissimilar in desiccation and pressing.

Desiccated ⟷ Cold Pressed

Undesiccated ⟷ Hot Pressed

B. A statistically pre-determined number of each group of cured specimens were then routed. This procedure involved a method whereby the flash, or cured adhesive which was squeezed out during pressing, was removed from the bond line. A mechanism developed by Mr. J.T. Zak of Convair Plant II, Process Control Laboratory, was used. Essentially the apparatus was made up of a small portable drill, stand and an adjustable router bit.

C. At this point, a fourth variable entered the test procedure. Groups of the previously processed specimens were selected to be tested for tensile shear strength within one day after they had been cured. A second group was retained for testing following one week of aging at room temperature.

D. Tensile shear strength data was obtained employing a Baldwin-Southwark Universal Testing Machine. Tests were made at the following temperatures: -67°F, 75°F and 300°F. The -67°F temperature was obtained with a cold box refrigerated with a methyl alcohol-dry ice mixture circulated through the heat exchangers provided in the box. Temperatures were determined with an iron-constantan thermocouple and a Leeds & Northrup potentiometer. A thermostat was used to maintain the test temperatures within ± 5°F.

A range on the testing machine was selected so that the breaking load would fall between 15 and 85% of full scale capacity. The testing machine had been calibrated previously to an accuracy of within 1%.

Self aligning grips were used to engage the outer 2 inches plus or minus 1/4 inch from each edge of the lap joint. Normal (room) temperature strength properties were determined no sooner than 3 minutes after the specimens reached equalibrium at a temperature range of 70° to 80°F. Not less than 3 minutes nor more than 8 minutes were used to bring the bonded area of the shear test specimen to 300°F after the specimen was otherwise ready for final shear testing. No longer than 8 minutes were employed to bring the bonded area to -67°F after the specimen was otherwise ready for low temperature testing.

VII. TEST PROCEDURE (Continued)

The test specimen was gripped tightly in the jaws of the testing machine with the jaws and specimen so aligned that the jaws were directly above each other and in such a position that an imaginary straight vertical line would pass through the center of the bonded area and through the points of suspension.

E. The fifth and last variable being evaluated concerned the rate of loading. As before, a statiscally pre-determined number of the specimens, processed to this point, were selected for testing at loads of 1200 and 2400 pounds per square inch per minute until failure.

The load at failure was recorded and expressed in pounds per square inch of actual shear area, calculated to the nearest 0.01 square inch.

The nature and percent of failure, such as cohesive failure (failure within the adhesive), adhesive failure (adhesive peeling from the metal), and the adhesive thickness was recorded for each specimen. Adhesive thickness was the micrometer thickness of the overall lap-joint less the combined micrometer thicknesses of the individual pieces of metal.

VIII. DISCUSSION OF PROCEDURE

A. The test method described in the foregoing was used instead of the method of break-a-way finger panels specified as an alternate in MIL-A-5090B "Adhesive, Airframe Structural, Metal to Metal" for the following reasons:

1. Break-a-way finger panels deviate greatly in flatness across their width.

2. Fingers cannot always be aligned to give a 1/2-inch overlap.

3. Edges of the finger specimens cannot be trimmed off and discarded.

4. It was believed that more uniform and reproducible results would be obtained by using .064"x4"x9" panels.

IX. RESULTS

A. The results of the deviation survey on the preparation and testing of tensile shear specimens are given in the tables of the Appendix.

In addition to the information obtained concerning humidity, pressing, routing, aging, and rate of loading on the specimens tested, the following general observations of the material and procedure were made:

IX. RESULTS (Continued)

1. Relative humidity of the surrounding atmosphere varies greatly from morning to evening, as well as from day to day. (Table IX)

2. Tape stored in its original air tight container had no dessicant to absorb moisture present within the container.

3. No accord was observed between platens of the curing press as they rose in temperature to 350°F. In the pressings made, the center platen always reached temperature before the other two platens.

4. Apparently little difficulty was experienced with finger marks and other contamination, as was to be expected with the precautions taken to insure cleanliness and good processing.

X. DISCUSSION OF RESULTS

An inspection of Tables VI and VII shows that of the 28 specimens tested for tensile shear strength at 75°F, -67°F, and 300°F, none failed to possess the adhesion necessary to pass the minimum requirements of MPS 47.08. Desiccation used in 14 of the 28 specimens resulted in very important increases in tensile shear strength at all temperatures. Present indications point toward continuing reduced tensile shear values unless immediate steps are taken to minimize the amount of moisture in the air, and the unnecessary exposure of the tape during lay-up operation.

The effect of hot or cold pressing on the tape was found to be not significant. It is believed, however, that a slow rise from ambient temperature to 350°F would give the volatiles inherent in the adhesive a better chance to escape.

The presence of "flash" definitely affects the shear strength properties of the specimens at -67°F. Average increases with flash removed at this temperature amounted to 885 psi. The condition is not quite as significant at 75° and 300°F, and can easily be explained on the basis of the brittleness of the tape at -67°. Unremoved flash at -67°F is a starting point for a peel type failure between metal and adhesive. This action is accelerated as the specimen bends at the edge of the lap due to the eccentricity of the joint.

X. DISCUSSION OF RESULTS (Continued)

With the introduction of a delay in testing of one week following curing, a slight reduction in strength was observed. However, this condition is not significant when compared to a variable such as humidity. Under normal conditions, this delay in testing will not be encountered because of the necessity of knowing the results of tensile shear testing for daily surface control purposes.

Tests at high and low rates of loading were made because of proposed revisions to the load rate in MIL-A-8431. Indications are that increased rate of loading will improve values obtained.

NOTE: The data presented in this report are recorded in Materials & Processes Laboratory Notebook No. 3005.

XI. DESIGN AND ANALYSIS OF THE EXPERIMENTAL PROGRAM

PROGRAM

The object of this experimental design was to accurately assess the effects of several variables relative to cleaning, bonding and testing specimens for tensile shear.

Briefly, the variables, or factors, to be investigated and their corresponding levels are the following:

	FACTOR	LEVEL
1.	Moisture on Tape, due to atmospheric humidity	Desiccation, exposed to humidity
2.	Flash	Flash not removed, flash removed
3.	Curing time after pressing	One day, one week
4.	Rate of loading	1200 psi/min, 2400 psi/min
5.	Initial temperature of the Press	Cold, Hot

According to the theory of design of experiments, the number of experimental combinations required to obtain estimates of the above five factors, at two levels each, and their corresponding interactions would be $2 \times 2 \times 2 \times 2 \times 2 = 32$. However, since only 28 samples could be obtained from the four joints available, some adjustment had to be made. By making the assumption that higher order interactions, i.e. interactions among three or more variables, are of the same degree of magnitude as the experimental error, a fractional factorial design requiring a total of 16 samples was constructed. The remaining 12 samples were utilized for obtaining a more accurate estimate of error, for making certain the assumption of insignificance of multifactor interdependences (or higher order interactions), and for checking on the consistency in direction of the effects of the factors considered. As indicated by its name, a fractional factorial design is used in situations where observations are expensive and, in order to lower the cost, the required number of experimental combinations needed for estimating the magnitude of all main effects and interactions is reduced to a fraction of the total. Information on the effect of higher order interactions is sacrificed, since these multifactor interdependences are usually of the same size as the experimental error.

The pattern formed by the data obtained in this problem is shown below. Each specimen is represented by a number from 1 to 28.

BLOCK DIAGRAM

		Flash Routed		Flash Kept	
		One Day Aging Time	One Week Aging Time	One Day Aging Time	One Week Aging Time
SAMPLES OF TAPE KEPT IN DESICCATOR	Cold Pressing	1, 2 (L)	4, 3 (L)	5 (L)	6 7
	Hot Pressing	16, 15 (L)	17, 20 (L) 18	19	21 (L)
SAMPLES OF TAPE EXPOSED TO HUMIDITY	Cold Pressing	9, 8 (L)	10, 14 (L) 11	12	13 (L)
	Hot Pressing	22, 26 (L)	24, 23 (L)	25 (L)	27 28

The analysis of the experimental data was done by means of an analysis of variance technique, which is an arithmetical method for positioning the total variation in an experiment into each of its component parts for the purpose of assessing the direction, magnitude, and significance of the effect of each variable.

Two analyses of variance for each of the three testing temperatures were constructed. Specimens numbered 1, 3, 5, 6, 7, 15, 17, 18, 19, 21, 8, 10, 11, 12, 13, 22, 23, 25, 27, and 28 were used for constructing the analyses of variance shown in Tables X, XI, and XII. These analyses of variance present the variation associated with each variable under investigation both as a magnitude of variability and as a per cent of the total variation. Results from specimens 1, 2, 3, 4, 15, 16, 17, 20, 8, 9, 10, 11, 14, 22, 23, 24, and 26 were used for constructing the three auxiliary analysis of variance shown in Table XIII. The object of these auxiliary analyses was to obtain a more refined estimate of experimental error and also to check assumptions as to the insignificance of higher order interaction effects.

* A letter (L) affixed to the specimen number means that a high rate of loading of 2400 psi/min was used for the specimen; otherwise the rate of load used was 1200 psi/min.

In the table shown below the low level of a factor is represented by the number zero, and the high level by the number one. The experimental combinations required (excluding repeats) for the analysis of variance on tables X, XI, and XII are those for which summing across each row one obtains a zero or an even number.

TOTAL EXPERIMENTAL COMBINATIONS

Experimental Combination Number*	Pressing	Moisture	Flash	Curing Time	Rate of Load	The Cross Experimental Combinations are Required for Fractional Design
1	0	0	0	0	0	X
2	1	0	0	0	0	
3	0	1	0	0	0	
4	1	1	0	0	0	X
5	0	0	1	0	0	
6	1	0	1	0	0	X
7	0	1	1	0	0	X
8	1	1	1	0	0	
9	0	0	0	1	0	
10	1	0	0	1	0	X
11	0	1	0	1	0	X
12	1	1	0	1	0	
13	0	0	1	1	0	X
14	1	0	1	1	0	
15	0	1	1	1	0	
16	1	1	1	1	0	
17	0	0	0	0	1	
18	1	0	0	0	1	X
19	0	1	0	0	1	X
20	1	1	0	0	1	
21	0	0	1	0	1	X
22	1	0	1	0	1	
23	0	1	1	0	1	
24	1	1	1	0	1	X
25	0	0	0	1	1	X
26	1	0	0	1	1	
27	0	1	0	1	1	
28	1	1	0	1	1	X
29	0	0	1	1	1	
30	1	0	1	1	1	X
31	0	1	1	1	1	X
32	1	1	1	1	1	

* The numbers of these experimental combinations do not correspond to the numbers given in the block diagram.

The above rule for obtaining the required experimental combinations is a direct consequence of the confounding relationship selected. A confounding relationship is the expression which indicates what effects are confounded (or mixed) with each other. The confounding relationship selected for the construction of this fractional factorial design is

$$I = P\,H\,R\,T\,L, \qquad (1)$$

which means that the overall average is confounded with the five factor interaction of pressing X humidity X routing X time X rate of loading. In order to find out what effect is confounded with the pressing effect (P), for instance, one would multiply both sides of equation (1) by P, obtaining

$$P \times I = + P \times (P\,H\,R\,T\,L) \qquad (3)$$

In the zero mod 2 system one has

$$P \times I = P, \text{ and}$$

$$P \times P = P^2 = I = \text{Unity} \qquad (4)$$

Therefore, substituting relationships (4) in (3), one obtains

$$P = H\,R\,T\,L, \qquad (5)$$

which says that the main effect of pressing (P) is confounded with the four factor interaction of humidity X routing X curing time X rate of load.

This procedure is used to determine which interactions are confounded with the other main effects, and how the interactions are confounded with one another.

The derivation of the required experimental combinations to satisfy above requirements has been merely sketched here. Detailed information on this subject may be found in the texts on experimental design and statistics listed in the bibliography.

XII. APPENDIX

TABLE I

*REPRODUCIBILITY (PRECISION) TABLE

TEST TEMP.	ABSENCE of HUMIDITY	UNCONTROLLED HUMIDITY
75°F	±528 PSI	±500 PSI
300°F	±151	±282
-67°F	±464	±624

*By Reproducibility is meant plus or minus twice the standard deviation.

TABLE II

TABLE OF LEAST SIGNIFICANT DIFFERENCES*

TEMPERATURE	P%	MAGNITUDE OF DIFFERENCE (L.S.D.)
75°F	5	525 PSI
75°F	1	1150 PSI
300°F	5	452 PSI
300°F	1	650 PSI
-67°F	5	1000 PSI
-67°F	1	1437 PSI

L.S.D. - A difference between two values will exceed the L.S.D's indicated, by chance alone, only P times out of a hundred.

*Assuming uncontrolled humidity.

TABLE III

SUMMARY OF THE EFFECTS OF FACTORS

INVESTIGATED ON TENSILE SHEAR AT 75°F

FACTOR	LEVEL				DIFFERENCE
Routing	No	4622 PSI	Yes	4811 PSI	+189 PSI
Time	1 Day	4821	1 Week	4612	-209
Load Rate	1200	4626	2400	4808	+182
Pressing	Cold	4798	Hot	4636	-162
Humidity	No	4856	Yes	4578	-278

L.S.D. is for average of 8 observations each.

L.S.D. (1%) = 267 PSI

L.S.D. (5%) = 185 PSI

TABLE IV

SUMMARY OF THE EFFECTS OF FACTORS

INVESTIGATED ON TENSILE SHEAR AT 300°F

FACTOR	LEVEL				DIFFERENCE
Routing	No	1731 PSI	Yes	1829 PSI	+98 PSI
Time	1 Day	1740	1 Week	1820	+80
Load Rate	1200	1712	2400	1848	+136
Pressing	Cold	1828	Hot	1732	-96
Humidity	No	1866	Yes	1694	-172

L.S.D. is for average of 8 observations each.

L.S.D. (1%) = 123 PSI

L.S.D. (5%) = 85 PSI

TABLE V

SUMMARY OF THE EFFECTS OF FACTORS

INVESTIGATED ON TENSILE SHEAR AT -67°F

1. Effect of Routing depends on humidity.

	ROUTING		
	FLASH KEPT	FLASH REMOVED	DIFFERENCE
Dessicated	3348 PSI	3855PSI	+507 PSI
Undessicated	3288	4550	+1262

2. Effect of Pressing depends on time lapse between curing & testing.

	PRESSING		
	COLD	HOT	DIFFERENCE
1 Day	4230 PSI	3355 PSI	-875 PSI
1 Week	3762	3692	-70

3. Effect of Humidity depends on the rate of loading used.

	HUMIDITY		
	ABSENT	PRESENT	DIFFERENCE
1200 PSI/Min.	3862 PSI	3718 PSI	-144 PSI
2400 PSI/Min.	3340	4120	+780

L.S.D. is for average of 4 observations each.

L.S.D. (1%) = 534 PSI

L.S.D. (5%) = 371 PSI

TABLE VI

PANEL PAIR	SPEC. #	HUMIDITY	PRESSING	ROUTING	AGING DAYS	RATE OF LOADING	TEST TEMPERATURE 75°F	300°F	-67°F
			DATE →				3/11/58	3/12/58	3/13/58
1	1	Dess.	Cold	No	1	1200	4962 PSI	1761 PSI	4538 PSI
	2	Dess.	Cold	No	1	2400	5096	1888	4306
	3	Dess.	Cold	No	7	2400	4856	1935	2704
	4	Dess.	Cold	No	7	1200	4875	1888	3442
	5	Dess.	Cold	Yes	1	2400	5375	2000	4346
	6	Dess.	Cold	Yes	7	1200	4721	1869	4423
	7	Dess.	Cold	Yes	7	1200	4875	1788	4481
2	8	Undess.	Cold	No	1	2400	4798	1627	3608
	9	Undess.	Cold	No	1	1200	4856	1612	2769
	10	Undess.	Cold	No	7	1200	4385	1712	3288
	11	Undess.	Cold	No	7	1200	4625	1785	3284
	12	Undess.	Cold	Yes	1	1200	4625	1754	4423
	13	Undess.	Cold	Yes	7	2400	4663	1942	4635
	14	Undess.	Cold	No	7	2400	4596	1900	3288

←Panels were sawed into specimens at this point.

TENSILE SHEAR EXPERIMENTAL DATA

TABLE VII

PANEL PAIR	SPEC. #	HUMIDITY	PRESSING	ROUTING	AGING DAYS	RATE OF LOADING	TEST TEMPERATURE 75°F	300°F	-67°F
			DATE ⟶				3/11/58	3/12/58	3/13/58
3	15	Dess.	Hot	No	1	2400	4558 PSI	1846 PSI	2973 PSI
	16	Dess.	Hot	No	1	1200	4913	1512	3469
	17	Dess.	Hot	No	7	1200	4615	1742	3181
	18	Dess.	Hot	No	7	1200	4635	1896	3758
	19	Dess.	Hot	Yes	1	1200	4894	1769	3312
	20	Dess.	Hot	No	7	2400	4885	1881	3000
	21	Dess.	Hot	Yes	7	2400	4865	1977	3342
4	22	Undess.	Hot	No	1	1200	4413	1454	2585
	23	Undess.	Hot	No	7	2400	4394	1746	3667
	24	Undess.	Hot	No	7	1200	4462	1569	3458
	25	Undess.	Hot	Yes	1	2400	4952	1692	4558
	26	Undess.	Hot	No	1	2400	4769	1485	3200
	27	Undess.	Hot	Yes	7	1200	4413	1627	4577
	28	Undess.	Hot	Yes	7	1200	4154	1558	4356

⟵ Panels were sawed into specimens at this point.

TENSILE SHEAR EXPERIMENTAL DATA

TABLE VIII

75°F				300°F				-67°F			
SPEC. NO.	FAILURE Coh.	Adh.	THICK Mils	SPEC. NO.	FAILURE Coh.	Adh.	THICK Mils	SPEC. NO.	FAILURE Coh.	Adh.	THICK Mils
1	70	30	8	1	70	30	8	1	0	100	7
2	70	30	8	2	80	20	7	2	0	100	7
3	90	10	6	3	80	20	7	3	0	100	8
4	80	20	7	4	70	30	7	4	0	100	7
5	70	30	8	5	70	30	7	5	0	100	7
6	80	20	7	6	70	30	7	6	0	100	8
7	80	20	8	7	80	20	6	7	0	100	8
8	70	30	8	8	70	30	8	8	0	100	8
9	60	40	6	9	80	20	8	9	0	100	7
10	80	20	6	10	90	10	8	10	0	100	8
11	70	30	8	11	90	10	8	11	0	100	8
12	60	40	8	12	90	10	7	12	0	100	7
13	80	20	8	13	90	10	9	13	0	100	8
14	90	10	7	14	80	20	8	14	0	100	8
15	85	15	8	15	70	30	8	15	0	100	7
16	60	40	7	16	80	20	7	16	0	100	7
17	80	20	8	17	50	50	8	17	0	100	7
18	80	20	8	18	60	40	8	18	0	100	7
19	50	50	6	19	70	30	8	19	0	100	7
20	90	10	8	20	70	30	7	20	0	100	8
21	70	30	7	21	70	30	7	21	0	100	7
22	90	10	6	22	90	10	8	22	0	100	8
23	80	20	7	23	90	10	8	23	0	100	9
24	80	20	8	24	90	10	8	24	0	100	8
25	80	20	7	25	90	10	8	25	0	100	8
26	70	30	7	26	90	10	6	26	0	100	8
27	90	10	7	27	90	10	8	27	0	100	7
28	90	10	7	28	90	10	9	28	0	100	8

TENSILE SHEAR EXPERIMENTAL DATA

TABLE IX

RELATIVE HUMIDITY DATA

U.S. WEATHER BUREAU - LINDBURGH FIELD

TIME	9March	10March	11March	12March	13March	14March
0	64	71	82	81	86	76
1	70	71	74	85	86	75
2	73	66	69	84	84	80
3	75	47	78	86	86	82
4	75	50	86	86	82	82
5	80	34	91	86	85	81
6	80	35	89	81	80	76
7	70	46	90	80	71	67
8	65	39	86	72	62	60
9	50	29	67	64	57	51
10	52	30	67	64	48	50
11	54	30	55	63	47	50
12	49	56	53	59	43	47
13	46	51	55	71	41	50
14	47	56	66	64	42	52
15	45	63	60	53	47	52
16	49	65	62	60	54	51
17	64	63	67	66	57	69
18	66	70	64	69	60	66
19	72	75	64	70	67	71
20	77	70	69	78	67	72
21	80	65	75	82	68	72
22	79	89	85	80	69	76
23	81	87	86	84	73	76
Precipitation	0	.13"	.35"	.05"	0	0
High - Low	81-45	89-29	91-53	86-53	86-41	82-47
Sunrise	Clear	Clear	Cloudy	Cloudy	Clear	Cloudy
Sunset	Clear	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy

TABLE X

ANALYSIS OF VARIANCE OF TENSILE SHEAR AT 75°F

Source of Variation	Degrees of Freedom	Magnitude of Variation	Per cent of Total Variation
Coating Flash (R)	1	1425	12.8%
Time after curing (T)	1	1743	15.6%
Rate of Loading (L)	1	1314	11.8%
Pressing (hot vs cold) (P)	1	1040	9.3%
Humidity (H)	1	3108 **	27.9% **
R X T interaction	1	315	2.8%
R X L interaction	1	588	5.3%
R X P interaction	1	352	3.2%
R X H interaction	1	23	.2%
T X L interaction	1	18	.2%
T X P interaction	1	233	2.1%
T X H interaction	1	23	.2%
L X P interaction	1	218	2.0%
L X H interaction	1	163	1.5%
P X H interaction	1	298	2.7%
Error	4	270	2.4%
Total	19		

** The probability of obtaining such a large variation, relative to the experimental error, is less than one in a hundred.

TABLE XI

ANALYSIS OF VARIANCE OF TENSILE SHEAR AT 300°F

Source of Variation	Degrees of Freedom	Magnitude of Variation	Per cent of Total Variation
Routing Flash (R)	1	380 *	11.6% *
Time after curing (T)	1	256	7.8%
Rate of Loading (L)	1	729 **	22.2% **
Pressing (hot vs cold) (P)	1	361 *	11.0% *
Humidity (H)	1	1190 **	36.2% **
R X T interaction	1	30	.9%
R X L interaction	1	6	.2%
R X P interaction	1	30	.9%
R X H interaction	1	16	.5%
T X L interaction	1	36	1.1%
T X P interaction	1	1	0 %
T X H interaction	1	90	2.7%
L X P interaction	1	49	1.5%
L X H interaction	1	12	.4%
P X H interaction	1	42	1.3%
Error	4	57	1.7%
Total	19		

* The probability of obtaining such a large variation, relative to the experimental error, is less than one in twenty.

** The probability of obtaining such a large variation, relative to the experimental error, is less than one in a hundred.

TABLE XII

ANALYSIS OF VARIANCE OF TENSILE SHEAR AT -67°F

Source of Variation	Degrees of Freedom	Magnitude of Variation	Per cent of Total Variation
Routing Flash (R)	1	31,329 **	38.8% **
Time after curing (T)	1	169	.2%
Rate of Loading (L)	1	144	.2%
Pressing (hot vs cold)(P)	1	8,930 **	11.0% **
Humidity (H)	1	4,032	5.0%
R X T interaction	1	900	1.1%
R X L interaction	1	400	.5%
R X P interaction	1	56	.1%
R X H interaction	1	5,700 **	7.0% **
T X L interaction	1	1,936	2.4%
T X P interaction	1	6,480 **	8.0% **
T X H interaction	1	4,032	5.0%
L X P interaction	1	3,192	4.0%
L X H interaction	1	8,556 **	10.6% **
P X H interaction	1	4,356	5.4%
Error	4	539	.7%
Total	19		

** The probability of obtaining such a large variation, relative to the experimental error, is less than one in a hundred.

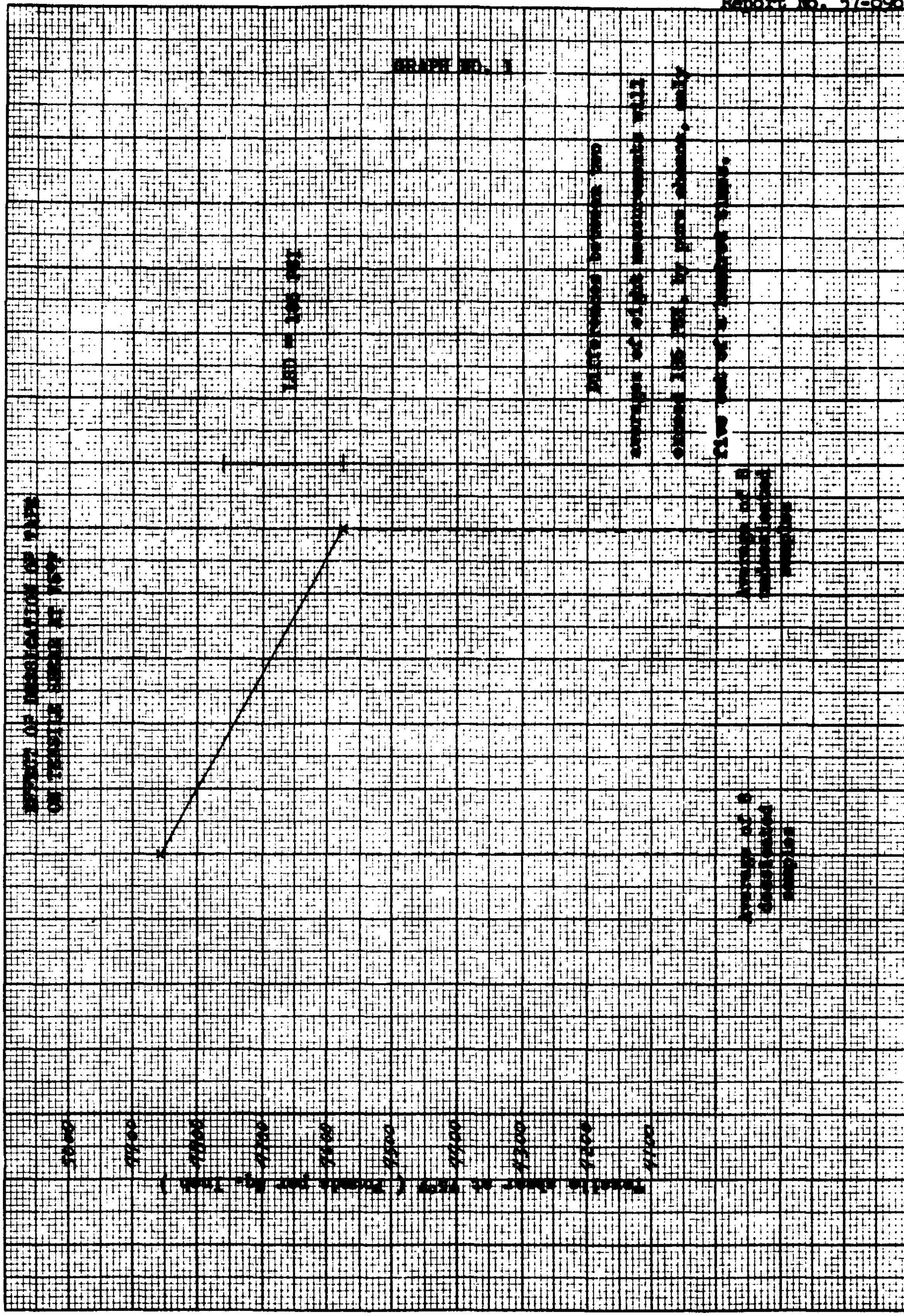
TABLE XIII

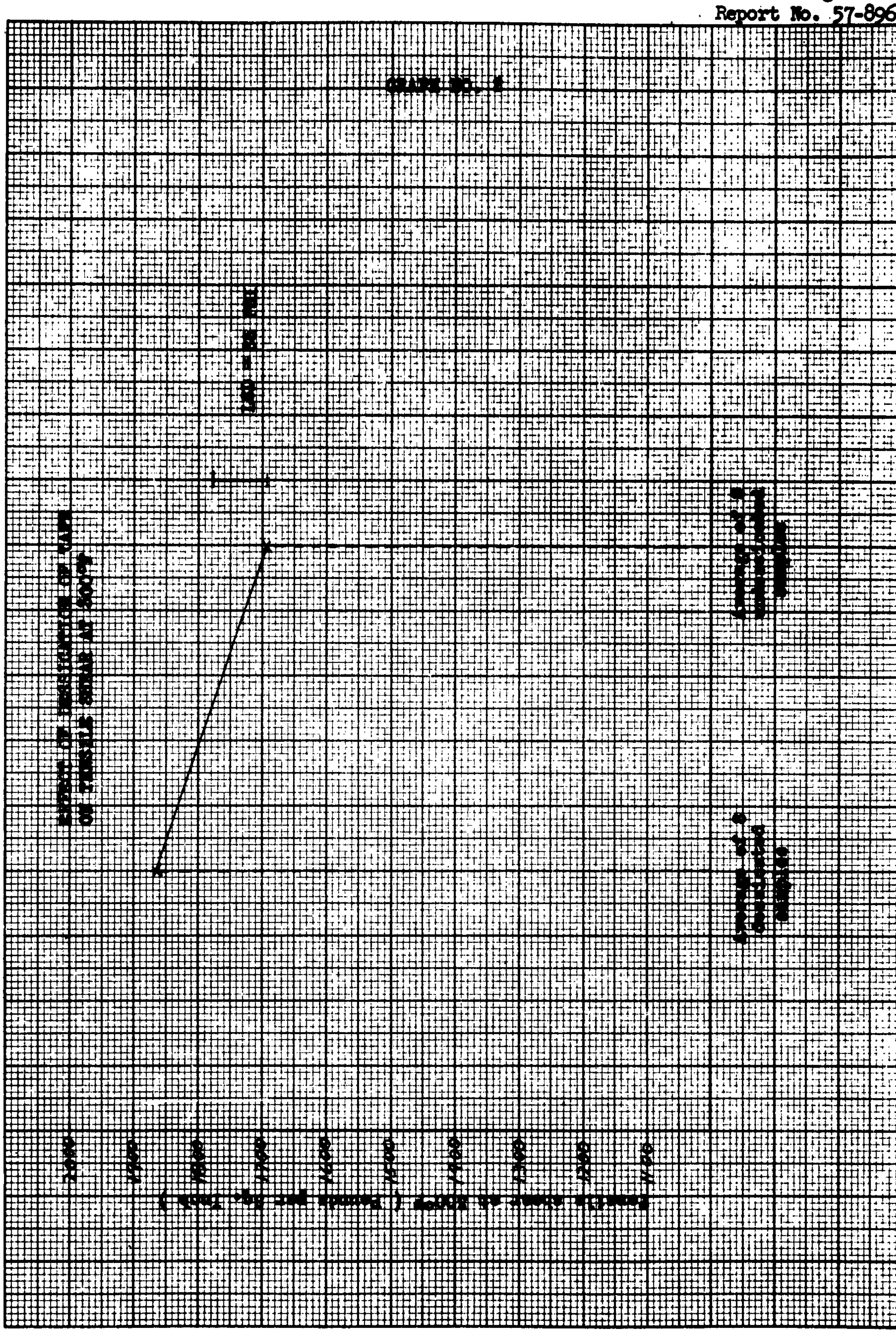
AUXILIARY ANALYSES OF VARIANCE

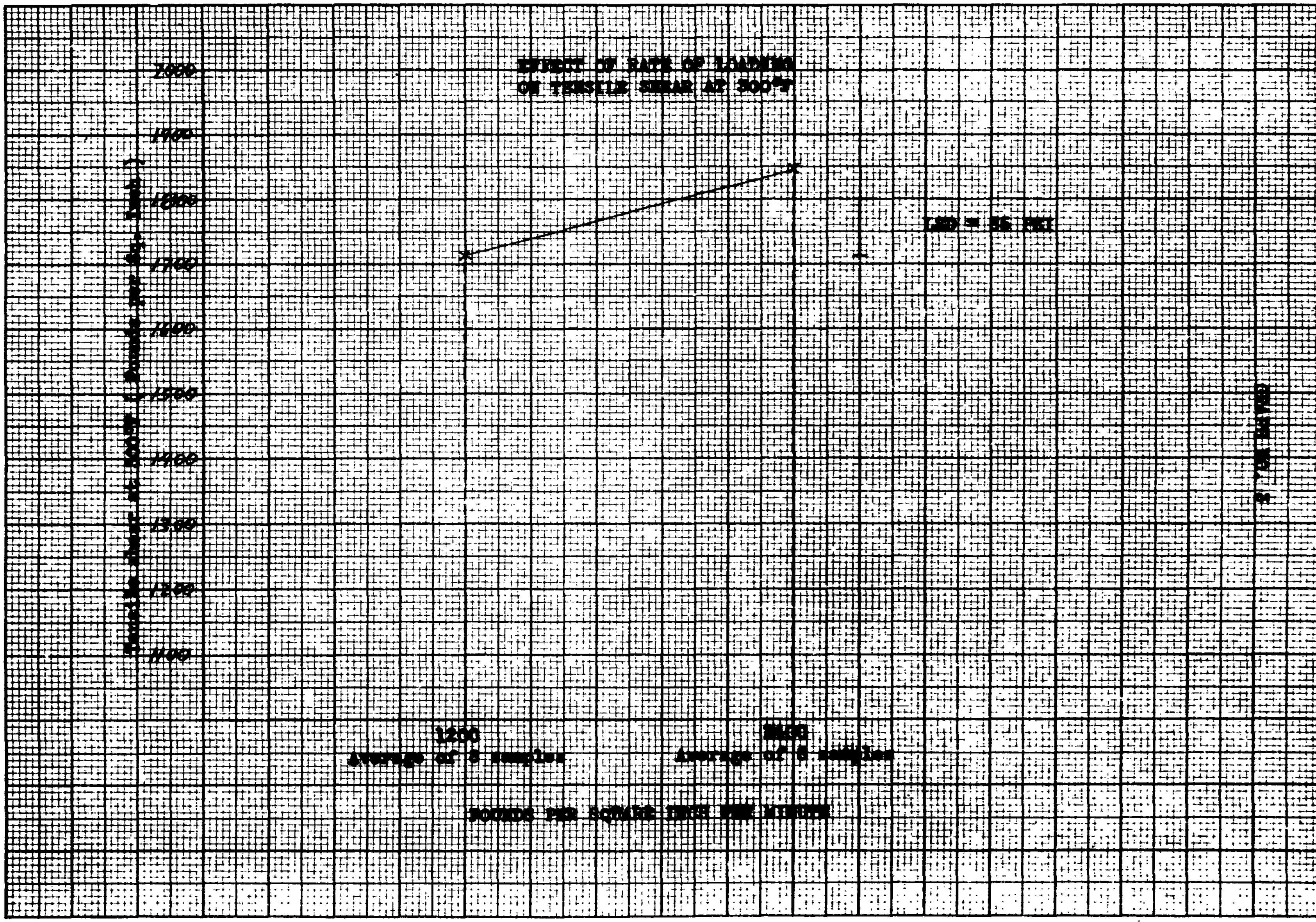
Source of Variation	Degrees of Freedom	Tensile Shear at 75°F	Tensile Shear at 300°F	Tensile Shear at -67°F
Time (T)	1	13.6	21.6 **	3.0
Rate of Load (L)	1	1.8	17.4 **	0
Pressing (P)	1	16.7	19.4 **	8.7
Humidity (H)	1	35.5 *	29.5 **	4.5
T X L interaction	1	.7	.1	3.1
T X P interaction	1	3.9	.2	19.2 **
T X H interaction	1	4.2	1.8	30.3 **
L X P interaction	1	0	1.6	.1
L X H interaction	1	1.4	.8	16.3 **
P X H interaction	1	.4	.1	8.0
T X L X P interaction	1	0	.4	2.4
T X L X H interaction	1	2.9	5.2	1.7
T X P X H interaction	1	0	.1	2.5
L X P X H interaction	1	.9	1.6	.1
T X L X P X H interaction	1	17.6	.2	.2
Total	15			

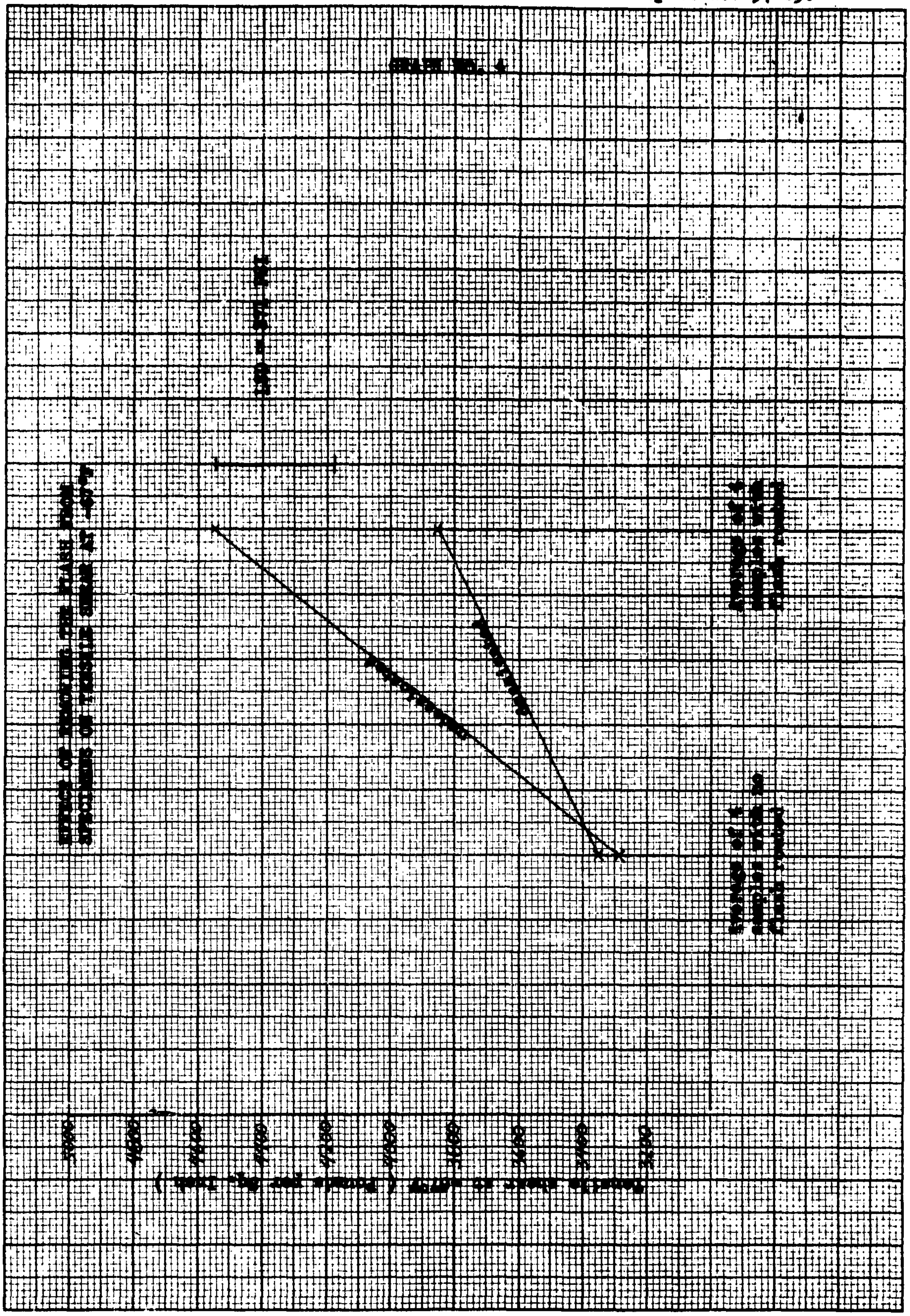
* The probability of obtaining such a large variation, relative to the experimental error, is less than one in twenty.

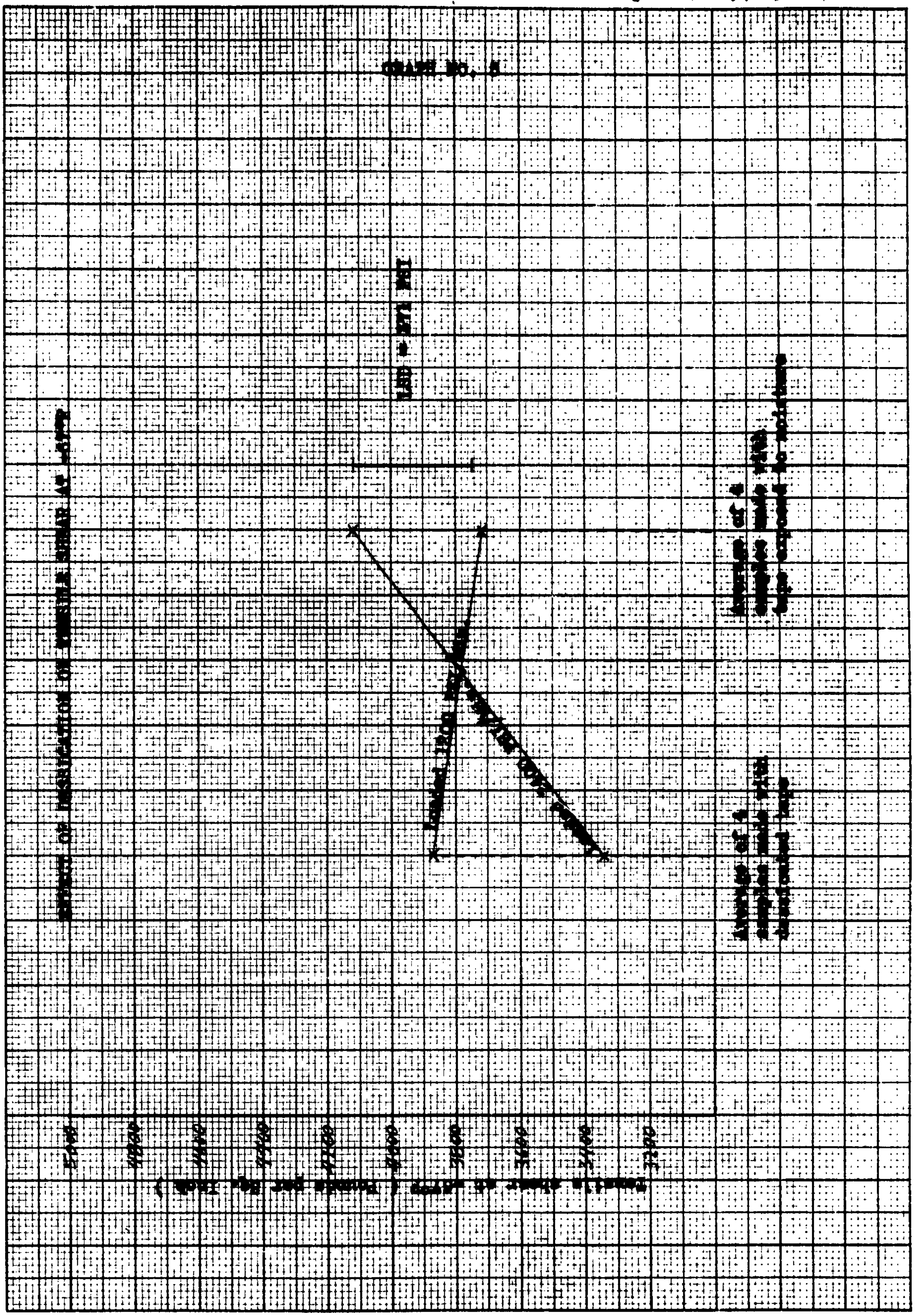
** The probability of obtaining such a large variation, relative to the experimental error, is less than one in a hundred.

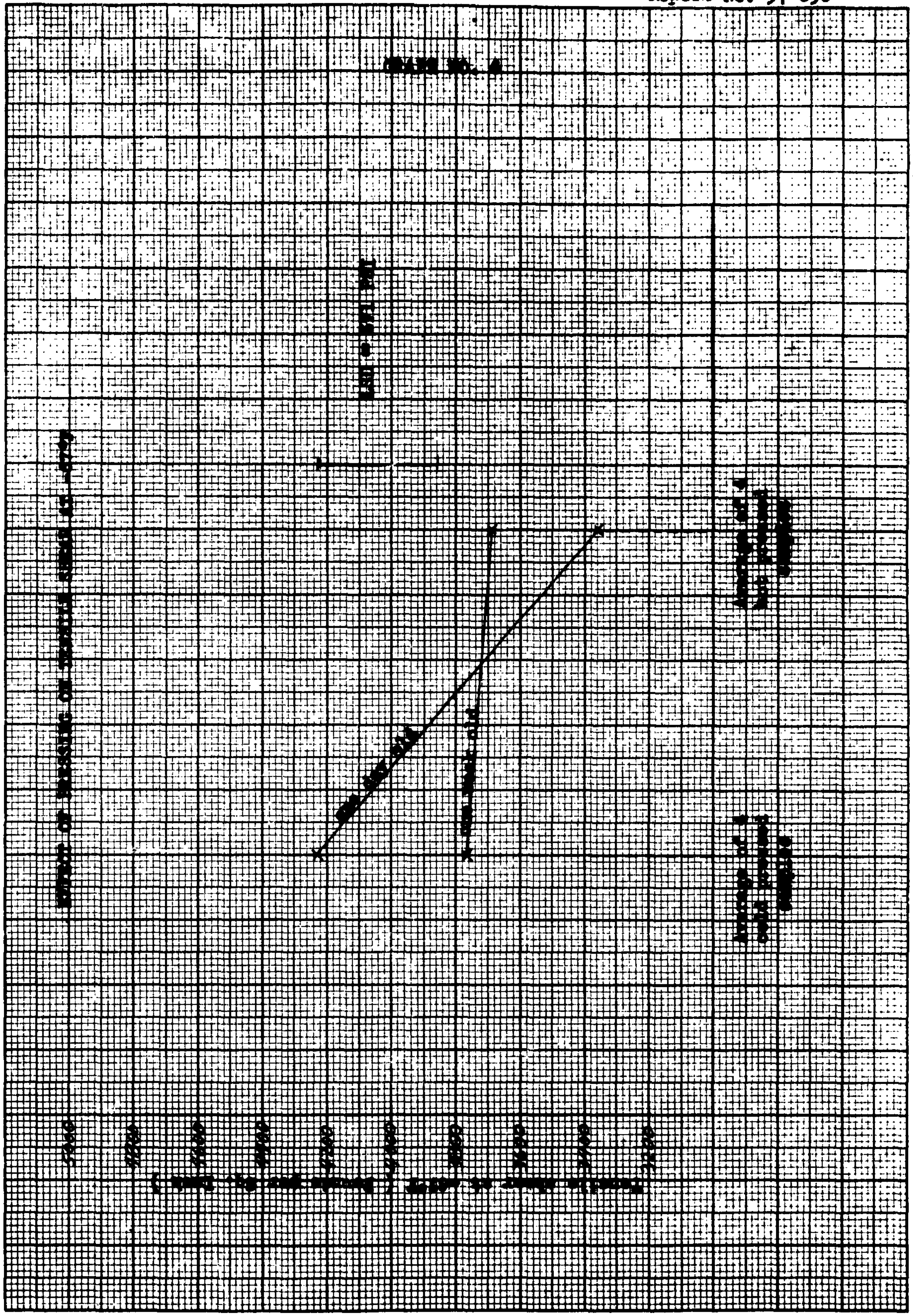

GRAPH NO. 1
EFFECT OF DESSICATION OF TAPE
ON TENSILE SHEAR AT 75°F
LSD = 185 PSI
Differences between two
averages of eight measurements will
exceed 185 PSI, by pure chance, only
five out of a hundred times.
Average of 8
Average of 8
samples
samples
8000
7900
7800
7700
7600
7500
7400
7300
7200
7100


2000
1900
1800
1700
1600
1500
1400
1300
1200
1100


EFFECT OF RATE OF LOADING
ON TENSILE SHEAR AT 300°F
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1200
POUNDS PER SQUARE INCH PER MINUTE




5000
4800
4600
4400
4200
4000
3800
3600
3400
3200
Loaded 1200 PSI/Min.
LSD = 271 PSI
Average of 4



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